USAARL Report No. 2000-03 AFDD/TR-00-A-001

Helicopter Pilot Estimation of Self-Altitude in a Degraded Visual Environment

John S. Crowley
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

Loran Haworth, Zoltan Szoboszlay, and Alan Lee
Aeroflightdynamics Directorate (AMRDEC)
U.S. Army Aviation and Missile Command
Ames Research Center
Moffett Field, California 94035-1000

September 2000

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about Laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Reg 70-25 on Use of Volunteers in Research.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 2000-03 AFDD/TR-00-A-001	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION See Block 16 — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS (City, State, and ZIP Code) U.S. Army Aeromedical Research Lab. -- Fort Rucker, AL; and Aeroflightdynamics Directorate -- Moffett Field, CA	7b. ADDRESS (City, State, and ZIP Code) 507 Scott Street Fort Detrick, MD 21702-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	30162787A879	OA	177

11. TITLE (Include Security Classification)
Helicopter Pilot Estimation of Self-Altitude in a Degraded Visual Environment (U)

12. PERSONAL AUTHOR(S)
John Crowley, Loran Haworth, Zoltan Szoboszlay, and Alan Lee

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM TO	2000 September	43

16. SUPPLEMENTAL NOTATION This report is a joint product done by the U.S. Army Aeromedical Research Laboratory at Fort Rucker, AL, and the Aeroflightdynamics Directorate (AMRDEC), Moffett Field, CA.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	helicopters, altitude perception/estimation, visual perception, flight safety, NVG, thermal imaging

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Human variability in self-altitude perception is well known, but the effect of night vision devices (NVDs) that provide a degraded visual image is unknown. Thirteen Army aviators with normal vision flew five flights (day, day-40° field-of-view (FOV), night vision goggle (NVG), NVG-right tube only, and Pilot's Night Vision Sensor (PNVS), a monocular thermal sensor) in a modified AH-1 Cobra helicopter. Subjects estimated their altitude or flew to specified altitude while flying a series of maneuvers. The results showed that the subjects were better at detecting and controlling changes in altitude (relative altitude estimation) than they were at flying to or naming a specific altitude (absolute altitude estimation). In cruise flight and descent, the subjects tended to fly above the desired altitude (underestimation), an error in the safe direction. While hovering, the direction of error was less predictable. In the low-level cruise flight scenario tested in this study, altitude control was affected more by changes in image resolution than by changes in FOV or ocularity. In hovering flight, altitude control was the worst while using the PNVS. This may be due to degraded image resolution, specific thermal image characteristics, or physical peculiarities of the PNVS system (continued)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE (Include Area Code) (334) 255-6907 — 22c. OFFICE SYMBOL MCMR-UAX-SS

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. (continued)

(e.g., parallax effects), but are probably not due to the monocular display or reduced FOV. This study examined only altitude estimation and control; nonetheless, the results do support the assertions of others in the literature that emphasis in helicopter helmet-mounted display (HMD) development should initially be placed on improvements in image resolution rather than FOV, given equivalent risk and cost. However, a rigorous study examining the effect of image resolution and FOV on more general aspects of flight performance is needed. Future HMD field research should endeavor to increase the sample size and to use subjects who are fully trained with all visual systems involved in the study to reduce ambiguity in data analysis.

Preface

Human use and ethics approval for this experiment was received on 19 September 1994 from the Human Research Coordinator and Medical Services Officer at NASA Ames Research Center, Moffett Field, California. This research was presented at the 1996 Aerospace Medical Association Annual Scientific Meeting in Atlanta, Georgia, and was funded jointly by the U.S. Army Aviation and Missile Command and the U.S. Army Aeromedical Research Laboratory.

Table of contents

List of appendices

Table of contents (continued)

List of tables

List of figures

Table of contents (continued)
List of figures (continued)

Table of contents (continued)

List of figures (continued)

Introduction

The estimation of self-altitude is a critical flight task, particularly in the low-altitude tactical helicopter environment. Recent surveys of U.S. Army accident data suggest that it is also a difficult task. From 1987-1995, there were 128 U.S. Army helicopter accidents in which the flight crew misjudged their height above the ground (Durnford, et al., 1995; Braithwaite, Groh, and Alvarez, 1997). The cost of these perceptual errors in lives and dollars is immense.

Considering all these accidents, it is surprising that previous height perception studies indicate that aviators tend to feel closer to the ground while flying than they really are--an error in the safer direction (termed under-estimation[1]) when descending and when flying at low altitudes (Armstrong et al., 1975; Foyle and Kaiser, 1991; Mizimoto and Utsugi, 1975; Ungs and Sangal, 1990). However, these effects become less predictable in sparse visual environments, such as provided by night vision devices (NVDs). It is known that NVDs currently fielded in the U.S. Army are associated with a relatively high aircraft accident rate (Durnford et al., 1995; Braithwaite, Groh, and Alvarez, 1997), but the effect of these tactically invaluable devices on in-flight height awareness has not previously been reported.

The two principal varieties of NVDs are thermal imaging and image intensification systems. In the U.S. Army, thermal imaging systems are used for piloting the AH-64 Apache helicopter (Rash, Verona, and Crowley, 1990). This system, called the Pilot's Night Vision Sensor (PNVS), provides a 30° x 40° monochromatic image to the pilot's right eye via a helmet display unit (HDU). The HDU attaches to a special flight helmet, comprising the Integrated Helmet and Display Sighting System (IHADSS) (Figure 1). Image intensification (I^2) systems, commonly called night vision goggles (NVGs), are used in a variety of aircraft, and generally provide a binocular monochromatic view of the world (Verona and Rash, 1989). The Aviator's Night Vision Imaging System (ANVIS) is the most prevalent NVG in modern U.S. Army aviation (Figure 2).

Compared to normal daytime visual cues, the image provided by present-day NVDs is degraded in several ways (Table 1). It is not clear, however, which aspects of visual scene content are critical for precise helicopter flight or height perception. Some research supports the view that resolution (i.e., visual acuity) is most important (Foyle and Kaiser, 1991), while other published studies suggest that field-of-view (FOV) must be maintained (Haworth et al., 1996), and Delucia and Task (1995) found that performance depends primarily on task and viewing condition.

---

[1]The terms "overestimation" and "underestimation" of altitude are easily confused. In this paper, "overestimation" connotes that the aviator believes that he is higher than he actually is (an error in the unsafe direction). "Underestimation" means that the aviator thinks he is closer to the terrain than he truly is (an error in the safer direction).

Table 1.
Comparison between I^2 and thermal imaging systems.

Parameter	ANVIS	PNVS
Field-of-view	40 degrees circular	30x40 degrees
Acuity	20/40 - 20/100	20/50 - 20/100
Color	Monochrome-green	Monochrome-green
Ocular	Binocular	Monocular-right eye

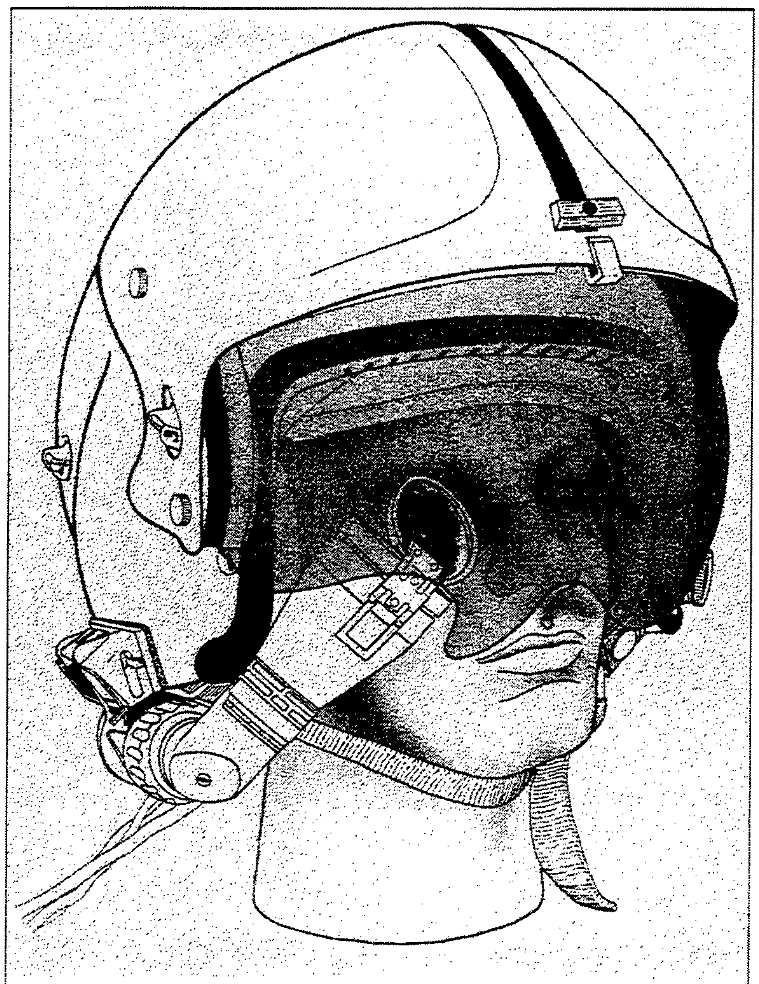

Figure 1. PNVS/IHADSS. The PNVS provides a head-tracked monochrome thermal image to the pilot's right eye from the perspective of the aircraft nose turret.

Figure 2. ANVIS. The ANVIS is based on 3rd generation image intensification technology, and provides binocular monochrome imagery.

I^2 and thermal imaging systems are, of course, based on very different sensor technologies, but as Table 1 shows, the visual limitations presented to the aviator by ANVIS and the PNVS are similar. Two obvious differences are that the ANVIS is binocular and a helmet-mounted sensor, while the PNVS is monocular and its sensor is located on the nose of the aircraft. Although the benefit of binocular vision in aviation is debatable (Tredici, 1996), it is certainly possible that height perception could be affected by the presence or absence of true stereopsis. Table 1 lists three factors that are potentially important to the accurate estimation of self-altitude: visual acuity, FOV, and stereopsis.

The objective of this study was to assess aviators' ability to judge height above terrain in a variety of reduced cue environments and flight modes. Using the basic method employed by Crowley et al. (1996) in a previous simulator-based study, altitude estimation ability over land in the daytime (unaided) environment was compared to that in the nighttime environment. Nighttime visual cues were presented by image intensifying night vision goggles (ANVIS) or by a thermal imaging system (PNVS). Adding two additional visual conditions (day 40° FOV and ANVIS monocular) allowed assessment of the importance of FOV, resolution, and binocularity in height perception. Obviously, an improved knowledge of the visual cues required for safe tactical NVD flight would be of great help to equipment designers, as well as training and safety professionals.

Methods

Subjects

Sixteen subjects were planned for this study, but only 13 were enrolled due to logistical and funding restrictions. Subjects were medically qualified Army aviators who were rated and current in the AH-1 aircraft and qualified with ANVIS (but not necessarily current).[2] Subjects were required to have 20/20 vision in each eye at distance and near (subjects requiring correction to achieve 20/20 were accepted if the method of correction was compatible with the HDU), and normal stereopsis as measured by Stereotest--Circles (Stereo Optical Co., Inc.).

Equipment

Aircraft

The study was flown in the NAH-1S research aircraft at the U.S. Army Aeroflightdynamics Test Directorate, NASA Ames Research Center, California. This aircraft, dubbed the "Flying Laboratory for Integrated Test and Evaluation" (FLITE), is a modified AH-1 surrogate trainer for the AH-64 Apache (Figure 3). The AH-1S is a two-place, tandem seat, single-engine attack helicopter with two-bladed main and anti-torque rotors, skid landing gear, and a maximum gross weight of 10,000 lbs. The FLITE aircraft incorporates a data acquisition system, a fixed forward turret-mounted color video camera, NVG-compatible lighting, and the PNVS (Hart, 1994). Additionally, the front cockpit cyclic is hydraulically boosted to move with less force than a standard AH-1 front seat cyclic control.

PNVS

The FLITE aircraft is outfitted with a fully functional production PNVS thermal imaging system. Symbols providing essential flight data, warnings, and navigational information can be superimposed on the PNVS video or the visual scene (Rash, Verona, and Crowley, 1990). The PNVS turret is head-slaved to the pilot's direct line-of-sight, with a maximum slew rate of 120 degrees/second.

[2]While the optimal subject would be qualified and current in the AH-1 aircraft, ANVIS, and PNVS, these requirements were logistically impossible (virtually no current AH-1 pilots are PNVS trained). Therefore, ANVIS-trained AH-1 pilots were recruited for this study, and were given a brief orientation (ground and air) to PNVS prior to data collection.

Night vision goggles

ANVIS is an NVD based on I^2 technology and is composed of two 3rd generation I^2 tubes worn in a binocular arrangement, providing a 40° FOV (Verona and Rash, 1989) (Table 1). In this study, ANVIS was worn in binocular and monocular configurations (described below).

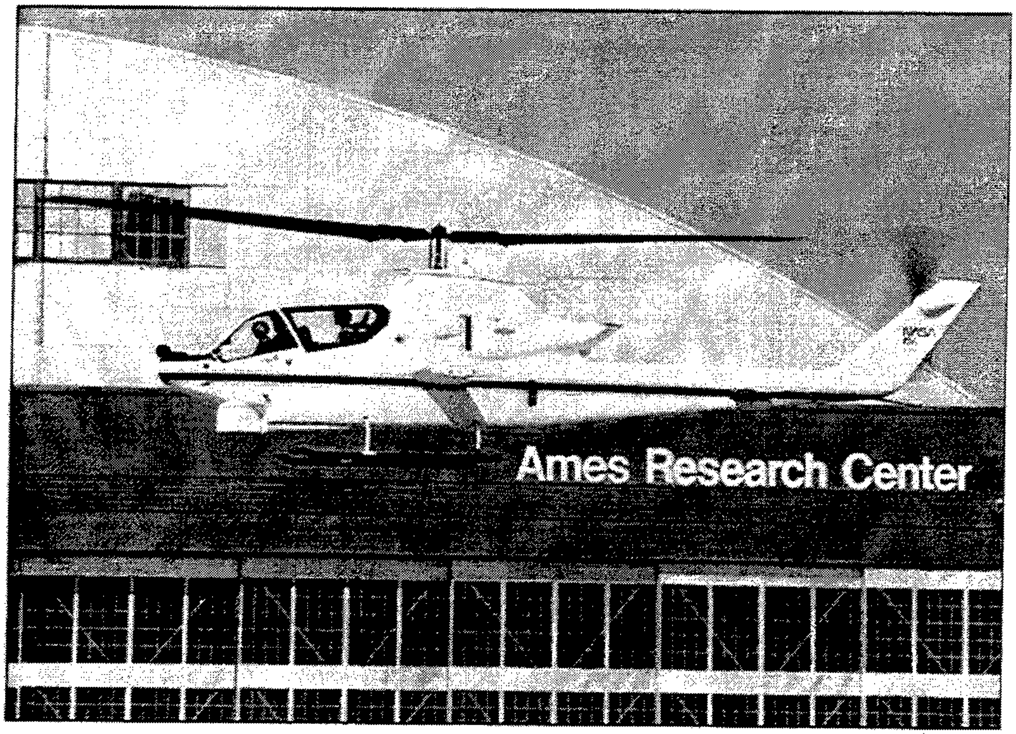

Figure 3. FLITE. The Flying Laboratory for Integrated Test and Evaluation (FLITE) test aircraft.

Experimental visual conditions

Each subject was exposed to five visual conditions, two in daylight and three at night (Table 2). During the day, all instruments providing altitude cues were covered. At night, subjects wore a helmet-mounted cloth curtain to prevent looking around the NVD at the cockpit or outside the aircraft (i.e., with unaided vision). PNVS symbology was turned off during data collection. For the daytime and ANVIS conditions, the subject occupied the front seat (copilot-gunner [CPG] station), which affords a better forward view, with the research pilot in the rear seat (pilot's station). For the PNVS iteration, the subject was required to occupy the rear seat of the NAH-1S aircraft, since the rear seat is the only station equipped with a head-tracking system used to position the PNVS sensor. The research pilot flew in the front seat for the PNVS iteration.

Table 2.
The five experimental conditions.

Visual condition	Time of day	Visual acuity	Field-of- view	Visual channels provided	Optics	Sensor location	Subject pilot location
Unaided	Day	20/20	Unrestricted	binocular	direct	head	front
40° FOV	Day	20/20	40° circular	binocular	direct	head	front
ANVIS-binocular	Night	20/40-100	40° circular	binocular	image intensifier	head	front
ANVIS-monocular	Night	20/40-100	40° circular	monocular	image intensifier	head	front
PNVS	Night	20/50-120	30° x 40°	monocular	thermal imager	turret	rear

Day-unrestricted condition

In the "day-unrestricted" condition, subjects wore a standard IHADSS flight helmet. The "out the window" view was unobscured.

Day-40° condition

To restrict the visual FOV to 40°, subjects wore a custom device mounted on the IHADSS flight helmet (Figure 4). This binocular device and the individualized fitting process have been successfully used in previous FLITE research (Haworth, et al., 1996).

ANVIS-binocular condition

In this nighttime configuration, the ANVIS was mounted on the flight helmet. Subjects were thus presented with a binocular 40° FOV.

ANVIS-monocular condition

To provide a monocular variation of the ANVIS condition, the left ANVIS tube was capped at both ends. Subjects wore the ANVIS assembly in the usual manner, thus providing an image-intensified 40° FOV to the right eye only.

PNVS condition

A monocular thermal image was provided by the PNVS and was displayed on an HDU mounted on a standard IHADSS helmet. This condition presented the aviator's right eye with a monochrome thermal image (Rash, Verona, and Crowley, 1990). As described above, the left eye was covered by a curtain to prevent unaided viewing with the left eye.

Figure 4. Helmet-mounted visor assembly. The helmet-mounted visor assembly used to restrict field-of-view in the day-40° condition (Haworth et al., 1996).

Study environment

Location

The study was flown over flat terrain at the Crows Landing Airfield located near Modesto, California (Figures 5 and 6).

Visibility and illumination

Since the data collection occurred over a period of several months, there was variation in length of day, sun position, etc. To partially control for this factor, day flights were scheduled to begin at the same time relative to sunset each day.

Data were collected only on dates on which the nighttime sky provided adequate illumination and thermal contrast. Predicted illuminance levels during scheduled ANVIS flights were between 0.0027 and 0.0323 lux, a range considered to encompass "medium" light levels (Rash, Vereen, and McLean, 1983). These predictions were based on light level calendars generated by U.S. Army Aeromedical Research Laboratory software, specific for the Crows Landing location (Rash, Vereen, and McLean, 1983).

Good thermal conditions were harder to quantify--in this study, the operational definitions used by Hart (1994) were applied. "Good" thermal conditions were presumed when a) during that day, there were clear or partly clear skies allowing at least a few hours of sunshine, and b) the research pilot, upon viewing the Crows Landing environment with the PNVS, judged the imagery to be of adequate quality to permit safe flight and the collection of useful data. Unacceptable thermal conditions were presumed when a) during the previous day, overcast weather with rain prevailed, and b) the research pilot assessed the PNVS imagery to be inferior. The final determination was left to the research pilot. Video recordings of the PNVS imagery allowed post-hoc review of thermal image quality. Although imprecise, this method is reasonable in the Crows Landing area, as thermal conditions are consistently excellent. No flights were cancelled because of poor thermal image conditions.

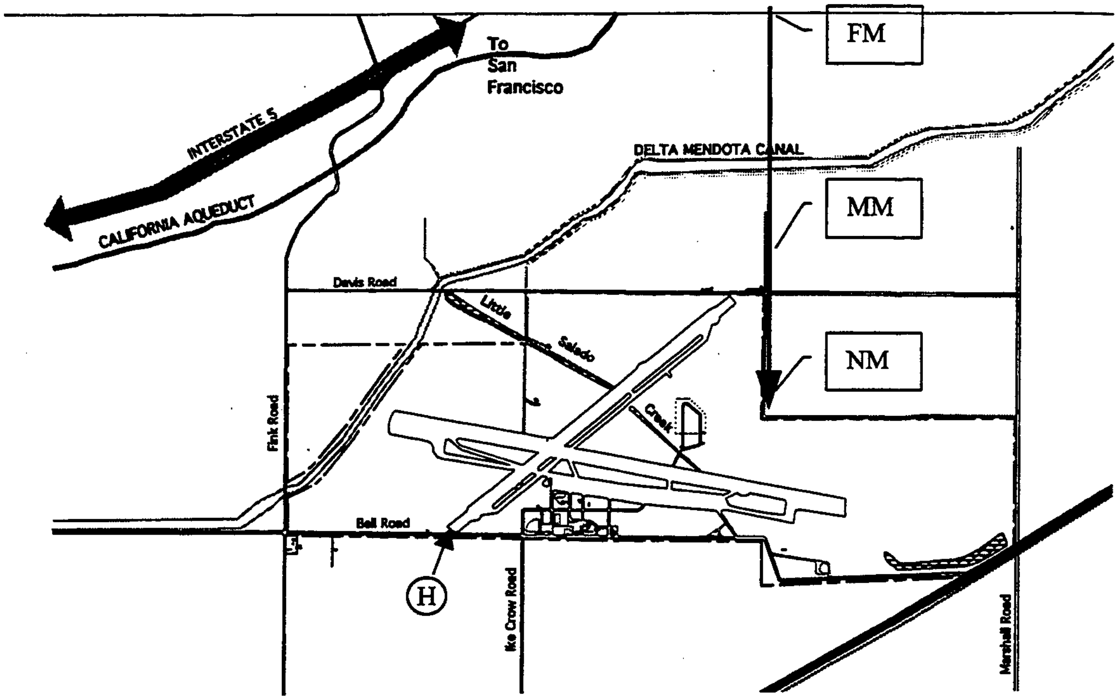

Figure 5. Crows Landing Federal Airfield. Diagram showing Crows Landing Federal Airfield, located near Modesto, California. The arrow marks the course flown during the cruise and approach phases (FM = far marker, MM = middle marker, NM = near marker, and 'H' indicates the location for the hovering maneuvers). Markers are described in Appendix A. While hovering, the research pilot maintained a 140° heading.

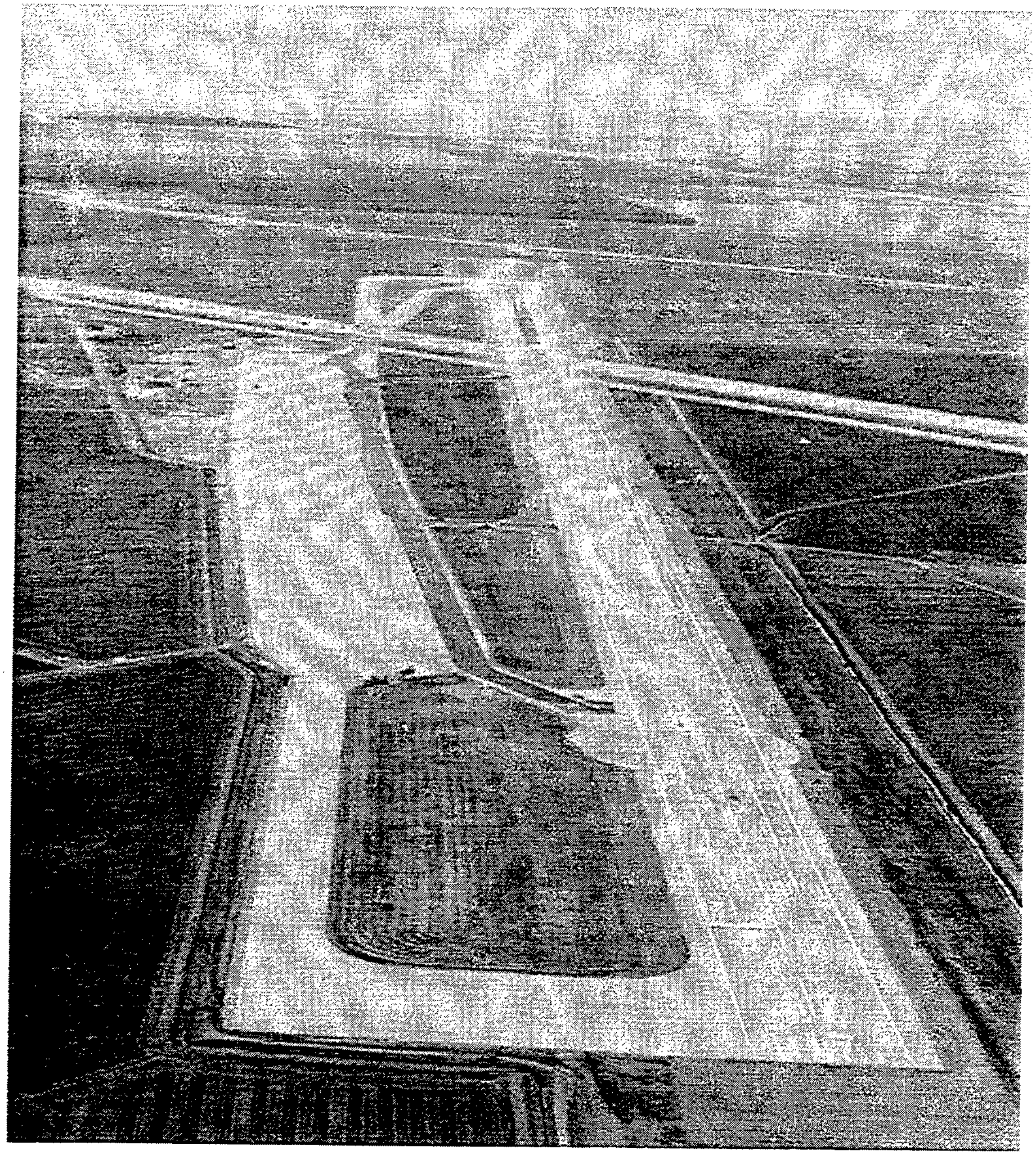

Figure 6. Aerial view of Crows Landing Federal Airfield.

Flight profile

The experiment consisted of three flight phases: cruise, approach, and hover (Table 3). Within the cruise and hover phases, there were two tasks: first, a descent maneuver, repeated three times, in which the subject's task was to fly the aircraft down to a specified altitude above ground level (AGL). The descent maneuvers were repeated three times because each provided only a single data point, which could be subject to significant variability. The second task within each phase was an altitude hold maneuver in which the subject was to maintain a pre-set (but unknown) altitude for 30 seconds. To increase the difficulty of the cruise altitude hold maneuver, the research pilot smoothly manipulated the cyclic to decrease airspeed by 10 kts to 70 kts (a slight pitch-up), then increasing airspeed to 90 kts (a slight pitch-down) and then returning to the target airspeed (80 kts). The effect of this control input was to change aircraft altitude. In order to maintain a constant altitude, the subject pilot was compelled to make compensatory collective control inputs.

In the approach phase, the subject was to fly a constant angle approach from a pre-set start point to an intended touchdown aim point. At three points along the approach, he was asked to give a verbal estimate of self-altitude. The approach was aborted at 150 ft AGL by the research pilot.

Table 3.
Phases of flight profile.

Maneuver	Task	Comments
Cruise phase		
Descent maneuver	Descend to 150 ft	Repeat 3 times, keep 80 kts.
Altitude hold maneuver	Maintain present altitude x 30 seconds	Research pilot inserts 5 deg pitch up/down, keep altitude 200 ft AGL
Approach phase	Fly normal approach and estimate altitude when asked (x3)	Airspeed constant 80 kts; start at 600 ft AGL, 1.6 miles out
Hover phase		
Descent maneuver	Descend to 15 ft	Repeat three times, at hover
Altitude hold maneuver	Maintain present altitude x 30 seconds	Altitude 20 ft AGL

The subject flew the profile once under each visual condition, for a total of five iterations (Table 2). Each iteration took about 30 minutes to fly. Feedback regarding the accuracy of the subject's estimates of self-altitude was not given. Radar altimeter data were recorded on board, along with a complete set of flight test parameters. The detailed flight profile and listing of flight test parameters are contained at Appendix A.

During all maneuvers, the subject was allowed to manipulate only the collective lever, thereby affecting altitude, while the research pilot maintained attitude, airspeed, hover position, and heading with the cyclic and pedals.

Procedure

Study timetables, custom-prepared for each day that satisfied lunar illumination criteria, were keyed to sunset time (to the nearest 1/2 hour) to control for time of year (Appendix B). Subjects thus had different reporting times, ranging from 1030 to 1300.

Upon arrival at NASA Ames Research Center, subjects were briefed on the purpose, risks and benefits of the study, and informed consent was obtained. Each subject completed an Initial Subject Questionnaire (Appendix C) for the purpose of collecting demographic information, and an abbreviated eye examination was performed by an investigator to ensure acceptable vision and stereopsis. The research pilot then briefed the subject on the flight profile, safety considerations, and dependent measures designed for this study. A brief thermal imagery training session followed, which included a PNVS video of the Crows Landing Airfield.

The research team was then transported to the Crows Landing Airfield by a NASA aircraft (approximately a 30-minute flight), where the subject received an orientation to the FLITE aircraft. Flight then commenced with the subject in the front seat of the FLITE aircraft and the research pilot in the rear. The research pilot allowed the subject to practice the required elements of the flight profile for 15 minutes (see Table 4). The subject completed the daytime unrestricted flight and landed. After affixing the FOV restricting device, the 40° FOV flight was accomplished. The aircraft then landed, and a brief orientation to the PNVS was conducted under ground power. The order of the two daytime flights was kept constant due to safety and time constraints.

At the prescribed time, the three nighttime conditions were flown in counterbalanced order, with the constraint that the PNVS flight was either first or last (to minimize seat changes). Prior to each ANVIS flight, the subject ensured best visual acuity by focusing on a distant object, according to standard U.S. Army guidelines (Headquarters, Department of the Army, 1988). Prior to the PNVS flight, the research pilot made a subjective determination whether the thermal environment was "adequate."

At the conclusion of the day's flying, the subject completed a short questionnaire (Appendix D), and the team was transported back to NASA Ames Research Center.

Table 4.

Sample daily study schedule.

Time	Activity
1200	Informed consent, eye exam
1230	FOV device fitting
1245	Flight profile briefing
1300	ANVIS/PNVS briefing
1330	IHADSS fitting
1415	Depart NASA Ames by NASA aircraft
1500	Preflight and orientation to FLITE aircraft
1530	Training flight and day data flight
1615	Day 40° flight
1645	Ground PNVS training
1700	Dinner
1830	Sunset
1830	Preflight/briefing
1845	ANVIS setup/focusing
1900	Night flight #1 (ANVIS)
1930	Night flight #2 (ANVIS mono)
2000	Night flight #3 (PNVS)
2115	Return to Moffett Field by NASA aircraft
2145	Arrive Moffett Field
2200	Subject debriefing and release

Data Analysis

The altitude estimation data were analyzed in separate 1-way repeated measures (RM) analyses of variance (ANOVA) with five levels of visual condition: Day, Day-40°, ANVIS, ANVIS-mono and PNVS. If the data failed normality or equal variance testing, a Friedman RM ANOVA on ranks was performed. Significant differences were followed up with pairwise multiple comparison procedures, using the Student-Newman-Keuls method. All analyses were done using Sigmastat® (Jandel Corporation).

For the cruise and hover descent tasks, the following variables were analyzed, using the mean of each subject's three trials: target altitude error (achieved - target altitude) and error magnitude (absolute value of target altitude error).

For the cruise and hover altitude hold tasks, the following variables were analyzed: error (average deviation from starting altitude over 30 seconds), error magnitude (absolute value of error), and altitude variability (standard deviation of altitude during task).

For the approach phase, the estimate error (estimated - true altitude) and error magnitude (absolute value of estimate error) were analyzed using a 2-way RM ANOVA on visual condition (five conditions) and distance from target (three distances). The approach flight path was analyzed using a 1-way RM ANOVA on the measured altitude 45 seconds into the approach (just prior to the inner marker) (Figure 5).

The effect of demographic and environmental variables (e.g., ANVIS flight time, previous PNVS experience, moon illumination) on performance was evaluated using simple t-tests, Mann-Whitney rank sum tests, or Pearson product moment correlation coefficients.

It is important to consider the possibility of alpha-error when interpreting the results of multiple statistical tests. In this analysis, 13 ANOVAs, 4 t-tests, and 16 correlation coefficients were calculated. Using Bonferroni's method of adjustment for multiple comparisons, statistical significance should not therefore be inferred from this experiment unless $p < 0.0015$ (Godfrey, 1986). However, we agree with Rothman (1986) that this adjustment may conceal real non-null associations, so all p-values less than 0.05 are reported as significant in this paper.

Results

Subject questionnaires

All 13 subjects were in good health, free of medication, and had normal visual function (6 wore spectacles). Subjects had an average of 108 hours of ANVIS flight time, and four had prior PNVS experience, although not within the past year (one subject with PNVS experience did not indicate the date of his most recent PNVS flight) (Table 5). Six subjects rated their depth perception as above average and seven as average.

Eleven subjects completed a postflight questionnaire (Appendix D). All stated that their prior ANVIS experience helped them; all seven respondents who had not used the PNVS stated that their lack of PNVS experience "hurt them" in the study. Two of these PNVS-naive subjects experienced motion sickness while using the PNVS. Postflight comments included "monocular cues were very different and difficult to adjust to," "least confident about PNVS calls," and "PNVS did not feel comfortable, but I liked the contrast it gives you."

Table 5.
Subject characteristics.

Subject no.	Demographic variable				
	Age (yrs)	Total Flight Hours	AH-1 Hours	NVG Hours	PNVS Hours
1	26	650	500	100	
2	34	2000	450	150	150
3	28	540	240	50	
4	31	650	515	63	
5	31	600	384	75	
6	34	1000	600	100	20
7	30	860	600	160	
8	49	7000	1200	75	150
9	47	1800	450	60	
10	34	500	450	75	
11	30	1400	1100	100	
12	32	3300	300	200	800
13	47	2800	800	200	
Average	35	1777	584	108	224

Descent maneuvers

There were no significant differences among visual test conditions in the cruise descent and hover descent maneuvers (Table 6). That is, subjects were not significantly more or less accurate in descending to a target altitude in any visual condition, whether in cruise or hovering flight. Figures 7, 8, 10 and 11 show an overall tendency to underestimate (i.e., fly higher than the target altitude) in both tasks. Figures 9 and 12 confirm that there were no differences in error magnitude (i.e., absolute value of error) among the five visual conditions.

Table 6.
Descent maneuvers: Results of 1-way RM ANOVA.

Maneuver	Variable	F	df	P
Cruise descent	Target altitude error	0.768	4,47	0.551
	Error magnitude	0.629	4,47	0.644
Hover descent	Target altitude error	1.0	4,46	0.416
	Error magnitude	0.568	4,46	0.687

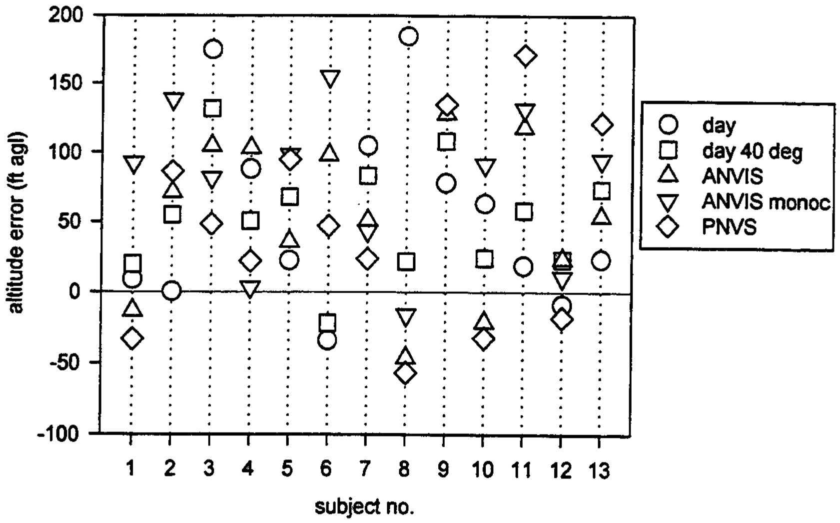

Figure 7. Individual target altitude error for the cruise descent maneuver. (Error = achieved altitude – target altitude.) Each symbol represents the mean error for three repetitions.

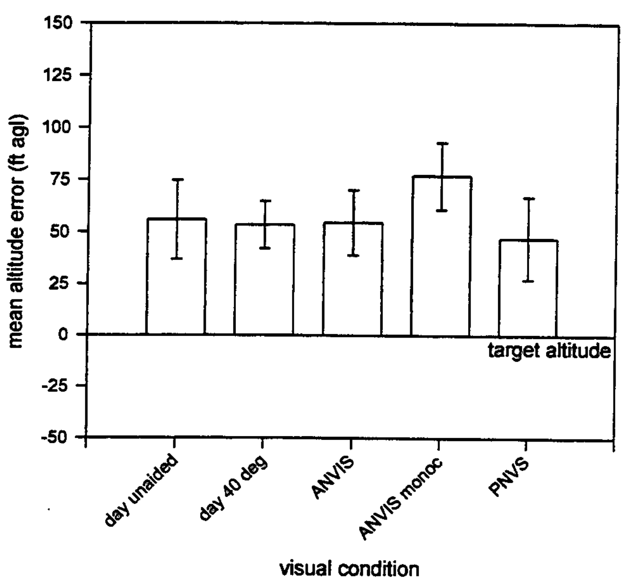

Figure 8. Mean target altitude error for cruise descent maneuver. (Error = achieved altitude - target altitude [150 ft].) Bars represent standard error of the mean. Analysis revealed no significant differences among conditions.

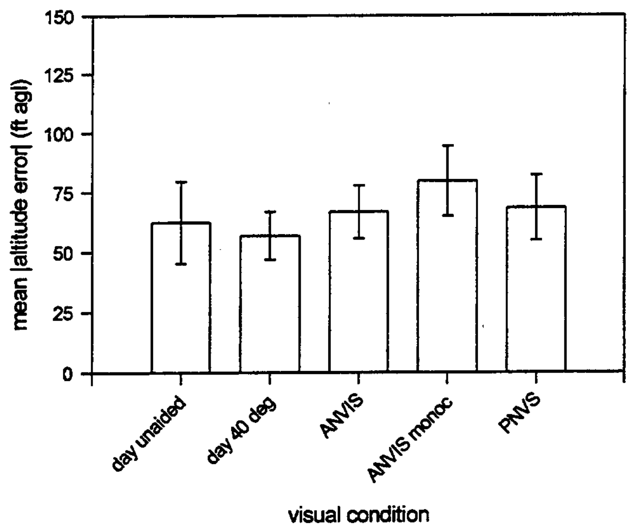

Figure 9. Mean error magnitude for cruise descent maneuver. (Error magnitude = | each target altitude error |.) Analysis revealed no significant differences among conditions.

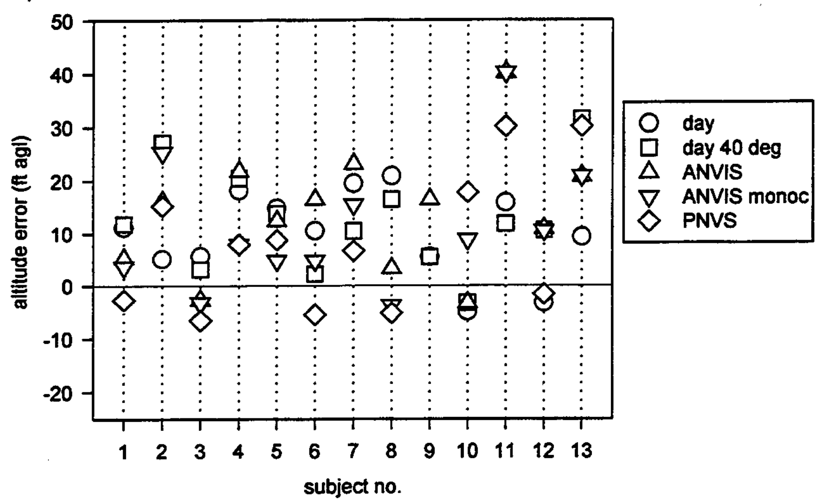

Figure 10. Individual target altitude errors for the hover descent maneuver. (Error = achieved altitude - target altitude.) Each symbol represents the mean error for three repetitions.

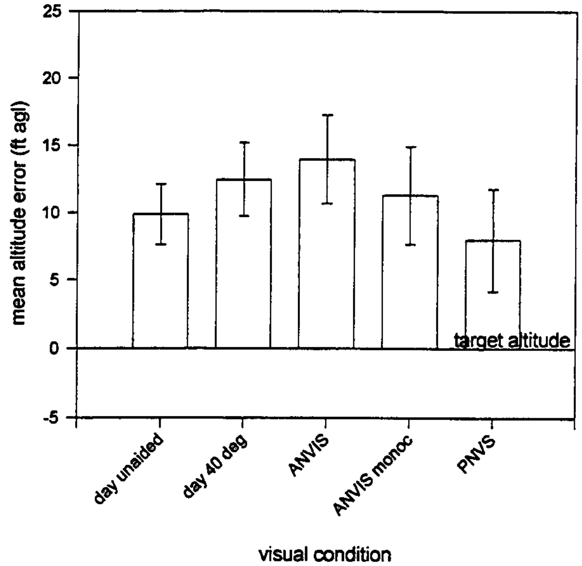

Figure 11. Mean target altitude error for hover descent maneuver. (Error = achieved altitude - target altitude.) Analysis revealed no significant differences among visual conditions.

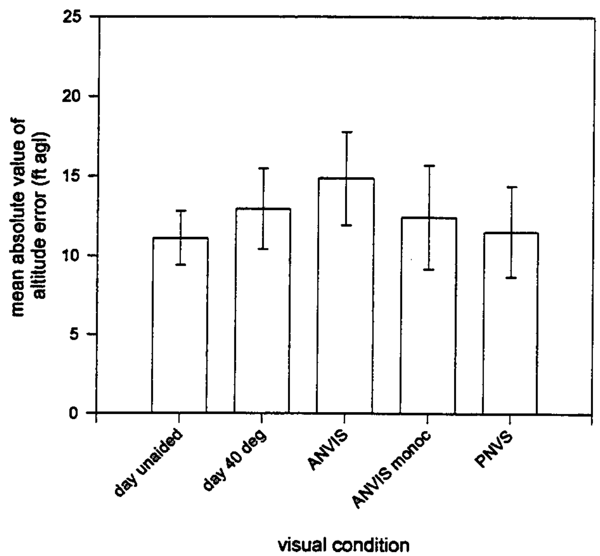

Figure 12. Mean error magnitude for hover descent maneuver. (Error magnitude = | each target altitude error |.) Analysis revealed no significant differences among conditions.

Approach maneuvers

When subjects were told to fly a constant angle approach to a target on the ground, only subtle differences in performance by condition emerged (Figure 13). At the 45-second point in the approach (just prior to the near marker), there was no significant difference in mean aircraft altitude among the five visual conditions ($F(4,42)=2.03$, $p=0.11$) (Figure 14). The lack of statistical significance is mostly due to subject variability, especially in the ANVIS monocular and PNVS conditions (Figure 15).

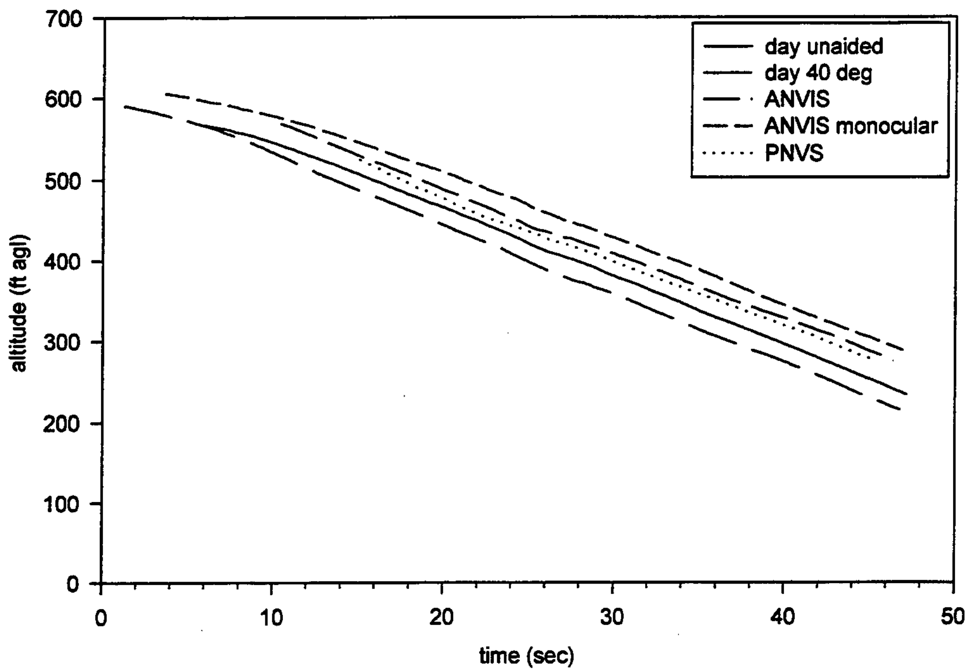

Figure 13. Mean flight paths by visual condition during approach maneuver. The approach began at a point 600 ft AGL and 1.62 miles from the point of intended touchdown.

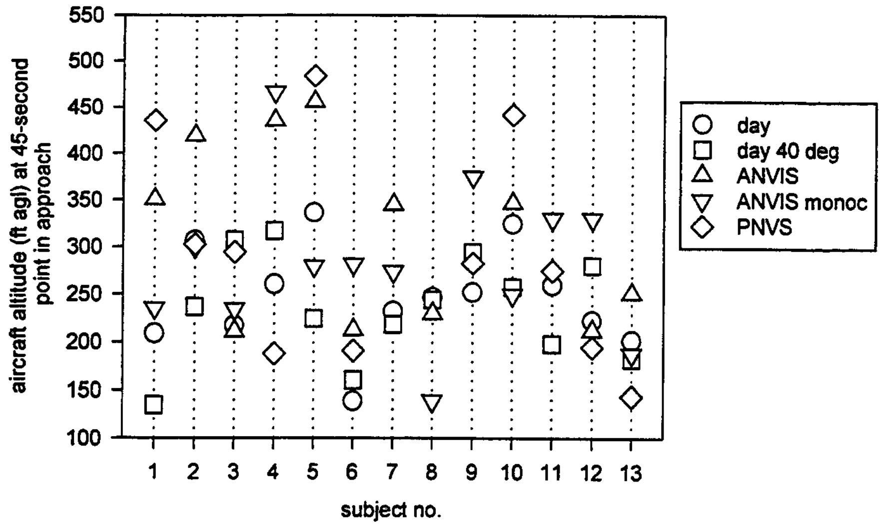

Figure 14. Attained altitude (ft AGL) for individual subjects at the 45-second point in the approach.

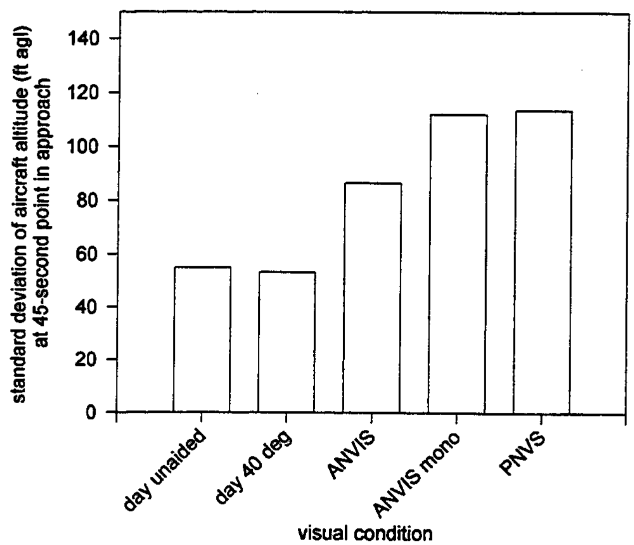

Figure 15. Within condition intersubject variability in aircraft altitude 45 seconds into the approach. Standard deviations were particularly high in the ANVIS monocular and PNVS conditions.

The other aspect of the approach phase required subjects to guess their altitude when prompted by the research pilot over three markers along the approach route. Analysis of this task was restricted to the nine subjects with complete data. There were no significant differences among visual conditions in the accuracy of these estimates (Figure 16), but error magnitude was significantly greater at the far marker, about 1 mile from the point of intended touchdown (Table 7 and Figure 17). It is not surprising that error magnitude should be greater at higher altitudes, as this is predicted by Weber's law (Coren, Porac, and Ward, 1978). Only in the ANVIS monocular condition did error magnitude not decline with decreasing altitude. There was an overall tendency to underestimate altitude throughout (Figure 16).

Table 7.
Altitude estimation during approach maneuver: Results of 2-way RM ANOVA.

Maneuver	Variable	Effect	F	df	p
Approach	error magnitude	marker location	3.78	2,64	0.045

See text for results of pairwise comparisons.

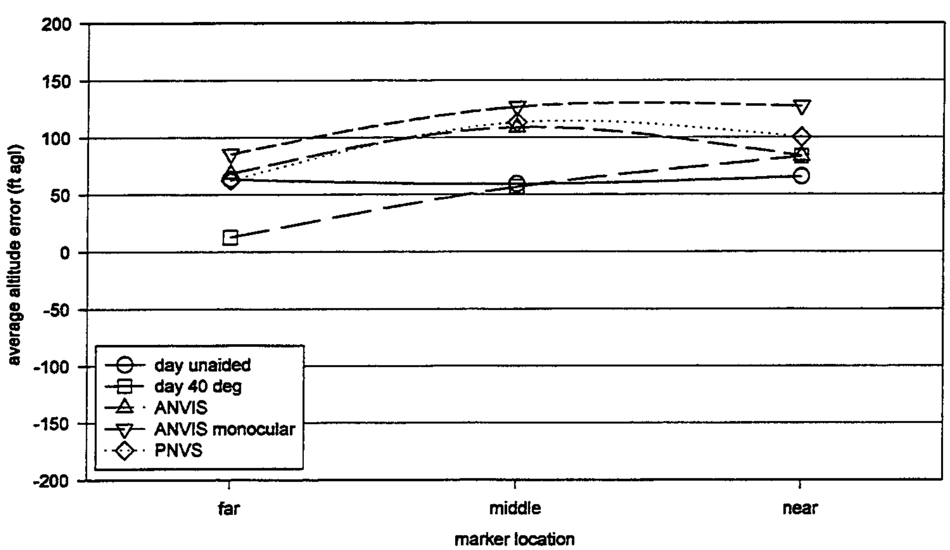

Figure 16. Mean altitude estimation error during approach. (Error = estimated altitude - true altitude.) Analysis revealed no significant differences among conditions.

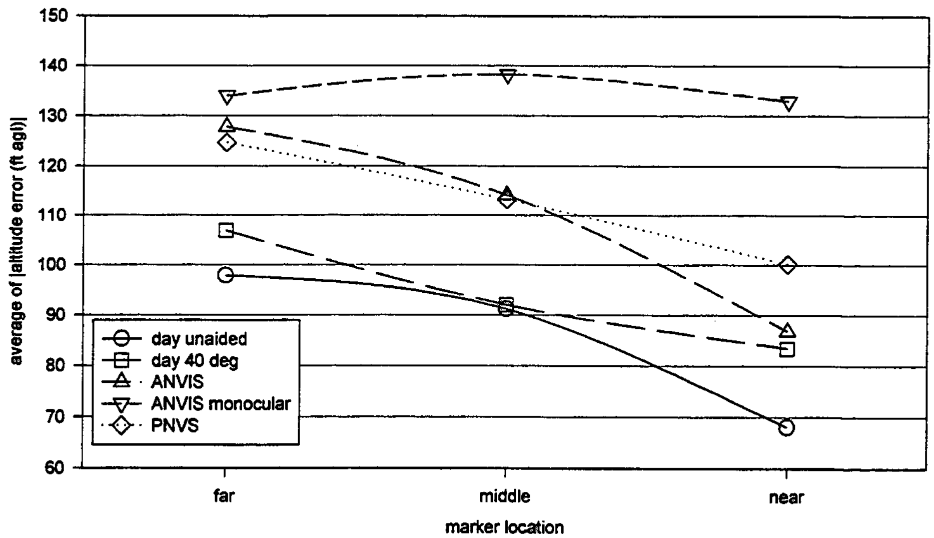

Figure 17. Magnitude of average altitude estimation error during approach maneuver. (Error magnitude = | target altitude error |.) Error magnitude was significantly greater at the far marker (see text).

Altitude hold maneuvers

Cruise altitude hold

Figures 18 and 19 show the large differences in flight path among the five visual conditions when subjects were asked to maintain a pre-set altitude. After normalizing for starting altitude, performance during the two daytime conditions appeared stable compared to the strong tendency to climb during the three nighttime conditions.

Mean standard deviation of barometric altitude over the 30-second period, reflecting the change or variability in altitude, was significantly larger in the PNVS and ANVIS monocular conditions than in either of the two daytime conditions (Table 8 and Figure 20).

The tendency to climb in the nighttime conditions was highlighted in the statistical analysis, which showed that subjects flew significantly higher in the PNVS and ANVIS monocular conditions than in either daytime condition (Table 8 and Figure 21). Further, the magnitude of altitude control error was significantly greater in the three nighttime conditions than in either day condition (Table 8 and Figure 22).

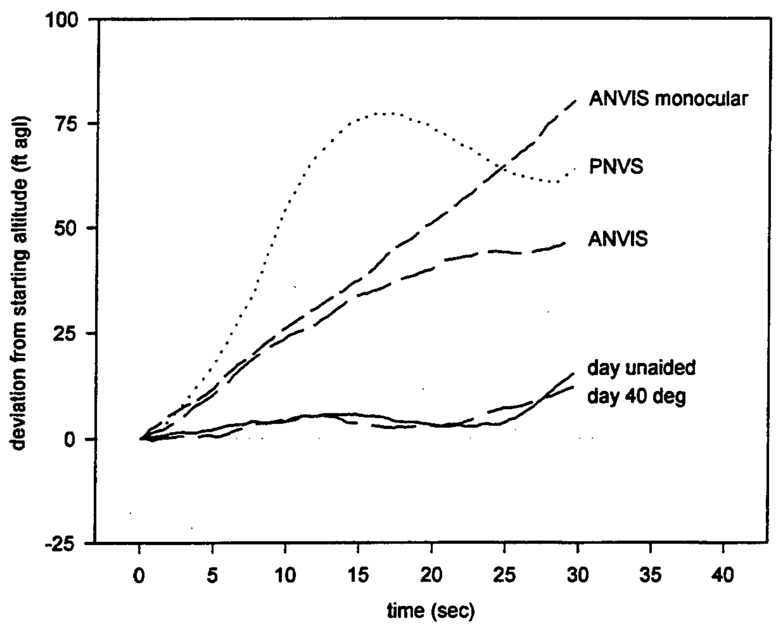

Figure 18. Mean flight paths by visual condition, showing deviation from level flight during cruise altitude hold maneuver.

Table 8.
Cruise altitude hold maneuver: Results of 1-way RM ANOVA.

Maneuver	Variable	F	df	p
Cruise	altitude sd	10.9	4,44	<0.001
	altitude control error	7.22	4,44	<0.001
	error magnitude*	χ^2=21	4	<0.001

* Friedman RM ANOVA on ranks. See text for results of pair-wise comparisons.

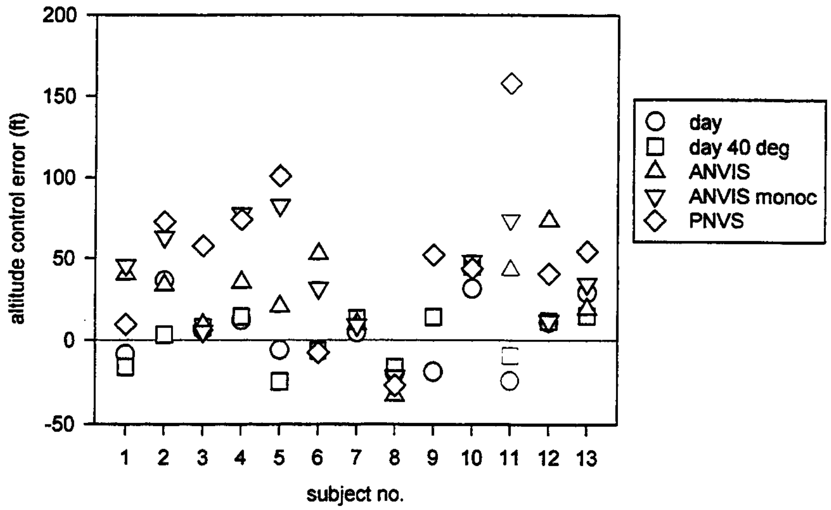

Figure 19. Cruise altitude control error for individual subjects, by visual condition. (Error = mean deviation from starting altitude over 30 seconds.)

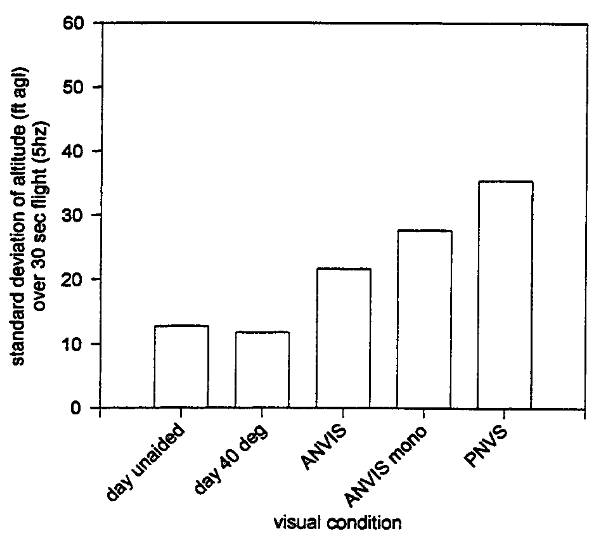

Figure 20. Flight path variability during cruise altitude hold maneuver. Bars represent mean standard deviation of barometric altitude over 30-second tasks, sampled at 5 Hz. Variability was significantly greater in the PNVS and ANVIS monocular conditions than in either daytime condition (see text).

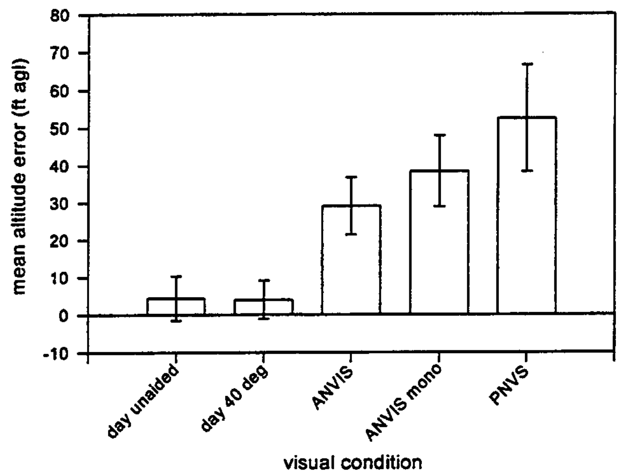

Figure 21. Mean altitude control error relative to start altitude during cruise altitude hold maneuver. Variability was significantly greater in the PNVS and ANVIS monocular conditions than in either daytime condition (see text).

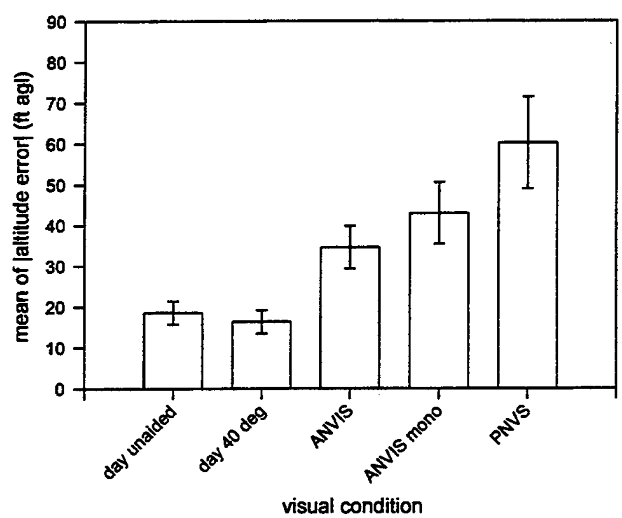

Figure 22. Magnitude of mean altitude control error during cruise altitude hold maneuver. Error was significantly greater in three nighttime conditions than in either day condition (see text).

Hover altitude hold

Figure 23 suggests that altitude control varied among the visual conditions, but subject variability dominated the analysis. Subjects were more likely to overestimate their altitude (i.e., an error in the unsafe direction) while hovering than in other study maneuvers (Figure 24). Altitude control was significantly more variable during the PNVS condition than any other (Table 9, Figure 25). There were no significant differences among visual conditions in altitude control error (Table 9, Figure 26), but the magnitude of altitude error (i.e., the absolute value of error) was significantly greater in the PNVS condition than in the other four conditions (Table 9, Figure 27).

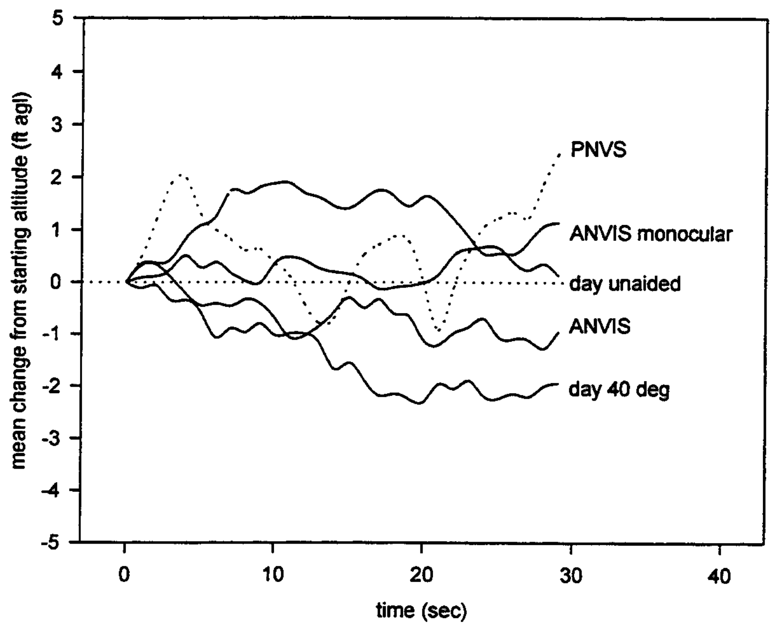

Figure 23. Mean altitude over time by visual condition, showing deviation from a level hover during hover altitude hold maneuver.

Table 9.
Hover altitude hold maneuver: Results of 1-way RM ANOVA.

Maneuver	Variable	F	df	p
Cruise	altitude sd	13.3	4,37	<0.001
	altitude control error*	χ^2=6.04	4	0.20
	error magnitude	5.7	4,42	<0.001

* Friedman RM ANOVA on ranks. See text for results of pairwise comparisons.

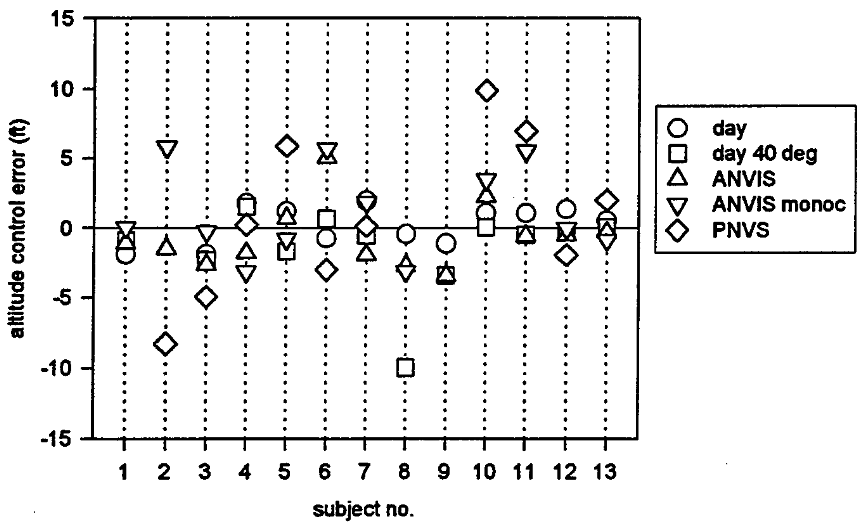

Figure 24. Hover altitude control error for individual subjects, by visual condition. (Error = mean deviation from starting altitude over 30 seconds.)

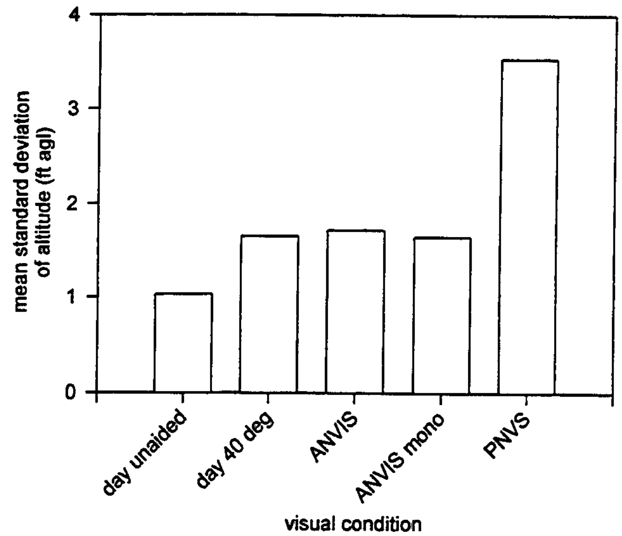

Figure 25. Radar altitude variability during hover altitude hold maneuver. Bars represent mean standard deviation of radar altitude over the 30-second task, sampled at 5 Hz. Variability was significantly greater during the PNVS condition than any other (see text).

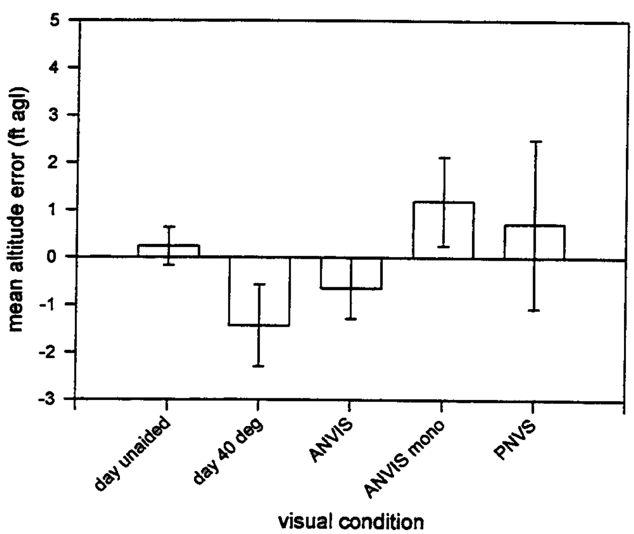

Figure 26. Mean altitude control error relative to start altitude during hover altitude hold maneuver. Analysis revealed no significant differences among conditions.

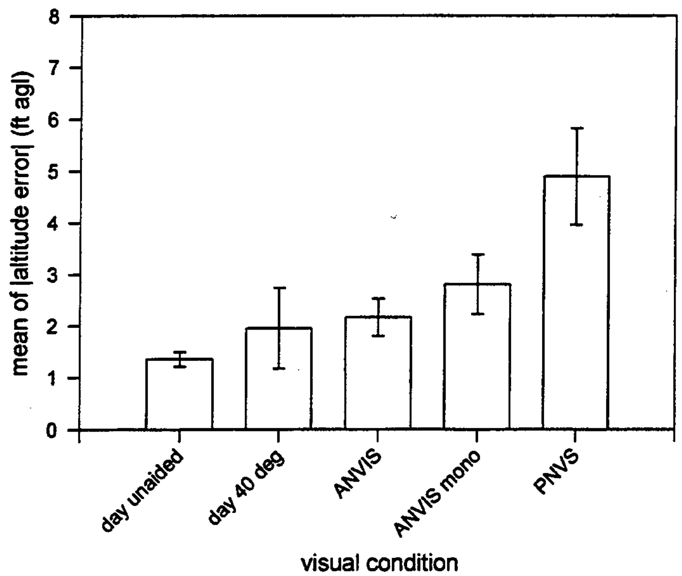

Figure 27. Magnitude of average altitude control error during hover altitude hold maneuver. Error was significantly greater during the PNVS condition than any other (see text).

Demographic and environmental correlations

Previous experience

There was no significant correlation between ANVIS flight time and altitude estimation performance on any ANVIS task ($p>0.05$). Nor was there any significant difference between subjects with PNVS (thermal sighting system) experience and those without, with respect to performance on the PNVS tasks (t-tests and Mann-Whitney rank sum tests, $p>0.05$).

Environmental variables

Factors affecting visibility (moon phase, moon elevation, PNVS condition rating) did not correlate with ANVIS or PNVS task performance ($p>0.05$).

Discussion

Between 1986 and 1996, according to Braithwaite, Groh, and Alvarez (1997), roughly 1.2 U.S. Army helicopters crashed per month because of aircrew errors in the estimation of altitude or height above the terrain. Accident epidemiology has revealed that these accidents are more common at night (Durnford et al., 1995; and Braithwaite, Groh, and Alvarez, 1997), but the specific role of modern night vision devices in height perception has not been subjected to experimental study. We designed the five visual conditions used in the present study (Table 2) with a specific intent to compare various aspects of NVD design with regard to in-flight altitude perception. For example, we thought that the effect of ocularity could be gauged by comparing the two monocular conditions (ANVIS-monocular and PNVS) with the other three conditions, which provide binocular cues. Similarly, the importance of resolution, field-of-view, etc., can be assessed. Despite methodological compromises inherent in field research, useful and interesting results were obtained.

General trends: underestimation vs. overestimation

Overall, our subjects tended to err on the safe side--underestimation. This corroborates the work of Mizumoto and Utsugi (1975), Ungs and Sangal (1990), and, where the altitudes were common to both studies, Armstrong et al.(1975). However, individual subjects occasionally erred in the unsafe direction, so this cannot be taken to mean that there is no hazard.

Reising and Martin (1995) speculated that some people might be biased toward underestimation while others may tend toward overestimation. In his study of horizontal distance estimation, 14 of 20 subjects underestimated, two overestimated, and two had no consistent bias. Summing our subjects' responses across maneuvers and visual condition, and using Reising's 75 percent criterion to classify distance estimation bias, we find that 6 of 13 subjects were underestimators, 1 was an overestimator, and 6 showed no clear bias. However, the trend was reversed within certain maneuvers: 4 of 13 subjects drifted downwards in the hover altitude hold maneuver, while only 1 showed a consistent tendency to drift higher (Figure 24).

Factors influencing altitude estimation performance

Task

In this study, we evaluated the subjects' ability to sense self-altitude in two general ways. First, they flew to a specified altitude, a test of 'absolute' altitude estimation, and second, they were asked to maintain an unknown pre-set altitude--a test of 'relative' altitude perception. The

'absolute' task requires some perceptual precalibration or training in order to make an estimate (i.e., what does 200 ft AGL look like?), whereas the 'relative' task mainly depends on simple detection of altitude change.

Our subjects were highly variable and imprecise in their ability to provide accurate estimates of absolute self-altitude, and no relevant differences were found among the five visual conditions for these tasks (cruise descent, hover descent, and approach). This is not surprising, as aviators are trained to visually recognize only a few specific altitudes (e.g., a 3-foot hover). Previous research suggests that this ability is readily learned (Crowley et al., 1996; Gibson and Bergmann, 1954; Niall, Reising, and Martin, 1999; Reising and Martin, 1995), but our subjects received no instruction in altitude estimation. This probably accounts for the lack of significant findings when subjects were asked to give a numerical estimate of self-altitude.

However, significant differences among visual conditions did emerge when the subjects were asked to maintain a constant altitude. Without a doubt, this is a more realistic and important flight task--seldom is a pilot asked to fly to a specified altitude without reference to instruments, but the military aviator flying at low altitudes must constantly monitor altitude above the terrain (Headquarters, Department of the Army, 1988). It is somewhat alarming that more subjects inadvertently descended (overestimated) while at a hover close to the terrain than while cruising at higher altitude, where the dominant pattern was an inadvertent climb (underestimation).

Visual condition

Resolution

Of the five visual conditions, the two flown in the daylight (day-unrestricted and day-40° FOV) provided the best visual resolution. Subject visual acuity while using the PNVS is difficult to quantify, but clearly, the resolution afforded in the PNVS and ANVIS conditions was inferior to that in daylight.

During the cruise altitude hold maneuver, subjects were significantly better at maintaining a constant altitude during the high-resolution conditions, compared to the three low-resolution conditions (Figures 18-22). Foyle and Kaiser (1991) reported a similar daylight advantage for horizontal distance estimation, compared to nighttime aided conditions. In our study, there also appears to be a subjective gradient related to resolution, ocularity, or both, within the low-resolution conditions (discussed below). The subjects' tendency to fly higher in low-resolution environments is in general agreement with a study of low-level flight performance in an F-16 flight simulator (De Maio et al., 1983).

Field of view

Only one visual condition provided a full and natural FOV (day-unrestricted), which is generally considered to encompass approximately 180° in the horizontal meridian, 110° of which is binocular (Tredici, 1996). The other four conditions restricted FOV to either a 40° circle (day-40° FOV, ANVIS and ANVIS monocular) or a 30° x 40° rectangle (PNVS).

Statistical analysis revealed no significant differences between the high-FOV and low-FOV conditions. The most 'pure' comparison in this case would be between the day-unrestricted and day-40° FOV conditions, and our subjects did appear slightly more variable in controlling hover altitude in the 40° condition than in the unrestricted condition (Figure 25), but no other differences were apparent. Foyle and Kaiser (1991), who used a similar FOV-restricting device, also found no effect of FOV on distance estimation in the horizontal plane.

It is interesting to compare these findings with those of De Maio et al. (1995) and Haworth et al. (1996), who found an increasing benefit of larger FOV on pilot performance. However, these were studies of complex flight performance, not just altitude estimation. De Maio et al. (1995), did not analyze altitude control separately, and Haworth et al. (1996) did not find diminished altitude control except at the smallest FOV studied (20° horizontal x 40° vertical).

In their review of design criteria for helicopter night pilotage sensors, Vollmerhausen and Nash (1989) presented the results of several unpublished studies, asserting that when acuity is maintained, flight performance is minimally affected by changes in FOV down to 23° x 38°. However, if resolution was degraded, increasing FOV resulted in little improvement in performance. They concluded "improving the image quality of current thermal imagers should take precedence over expanding the sensor FOV." It appears that manipulating only one variable in an experiment may fail to reveal important interactions (e.g., between FOV and resolution).

Ocularity

In the present study, there were two conditions that provided monocular visual input (ANVIS-monocular and PNVS), and three that provided binocular input (day-unrestricted, day-40° FOV, and ANVIS).

In no case were both monocular conditions significantly different from all three binocular conditions. The most 'pure' comparison in this case would be between the ANVIS and ANVIS-monocular conditions, and no differences were detected here. As discussed above, it does appear that there was a subjective performance gradient in the cruise altitude hold task representing a combination of resolution and ocularity (Figures 19-21), but this was not borne out in the statistical analysis.

Miscellaneous factors

In the hover altitude hold maneuver, altitude control was significantly worse in the PNVS condition, compared to the other four conditions (Figures 24 and 26). There are several factors that could explain this. First, the PNVS is based on a thermal imaging system, which presents the pilot with a different set of cues, and a generally degraded image, compared to vision with the naked eye or ANVIS (Table 1). Second, the PNVS sensor is mounted on the aircraft nose turret, which can generate visual parallax effects that would be disconcerting, particularly at low altitudes (i.e., while hovering). Nine of our 13 subjects were completely naive with respect to the PNVS system, so lack of training may have been a factor. However, the novel aspects of hovering with PNVS were minimized by only permitting them to manipulate the collective, maximizing their focus on the altitude estimation task. Although no performance differences were found between the nine naive subjects and the four with PNVS experience on thermal imaging-related tasks, Rothman (1986) points out that it is not possible to rule out confounding effects using statistical tests.

Caveats

It is possible, of course, that other factors may have accounted for these findings. For example, the cues presented by a thermal imaging system are very different from those encountered in the daylight or when using NVGs (Rash, Verona, and Crowley, 1990). As discussed above, it is possible that the novelty of these cues (i.e., to these subjects) accounted for the poorer altitude perception in this condition. Alternatively, there may be something unique about the rear cockpit (used only for the PNVS condition) that caused inferior performance, although it is more likely that the reverse is true, since the handling qualities are superior in the rear cockpit. Another potential source of bias relates to the longevity of the study. Over the 1 1/2 years of data collection, the terrain around the airfield varied considerably, as fields were planted and harvested. Thermal imaging is probably more sensitive to these changes in terrain; this factor could have injected more “noise” into the PNVS data than into data from the other visual conditions. However, the within-subjects design of this study mitigates this effect.

Conclusions

First, subjects were better at detecting and controlling changes in altitude (relative altitude estimation) than they were at flying to or naming a specific altitude (absolute altitude estimation).

Second, in cruise flight and descent, subjects tended to fly above the desired altitude (underestimation), an error in the safe direction. While hovering, the direction of error was less predictable.

Third, in the low-level cruise flight scenario tested in this study, altitude control was affected more by changes in image resolution than by changes in FOV or ocularity.

Fourth, in hovering flight, altitude control was the worst while using the PNVS. This may be due to degraded image resolution, specific thermal image characteristics, or physical peculiarities of the PNVS system (e.g., parallax effects), but are probably not due to the monocular display or reduced FOV.

Fifth, this study examined only altitude estimation and control; nonetheless, the results do support the assertions of others in the literature that emphasis in helicopter helmet-mounted display (HMD) development should initially be placed on improvements in image resolution. However, a rigorous study examining the effect of image resolution and FOV on more general aspects of flight performance is needed.

Sixth, although it simply was not feasible in this study, future HMD field research should endeavor to increase the sample size and to use subjects who are fully trained with all visual systems involved in the study, to reduce ambiguity in data analysis.

References

Armstrong, R.N., Hofmann, M.A., Sanders, M.G., Stone, L.W., and Bowen, C.A. 1975. Perceived velocity judgements and altitude judgements during rotary wing aircraft flight. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

Braithwaite, M., Groh. S., and Alvarez, E. 1997. Spatial disorientation in U.S. Army helicopter accidents: an update of the 1987-92 survey to include 1993-1995. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-13.

Coren, S., Porac, C., and Ward, L.M. 1978. Sensation and perception. New York: Academic Press.

Crowley, J.S., Caldwell, J.L., Sessions, M., and Tibbetts, C.R. 1996. Altitude estimation in the UH-60 flight simulator. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 96-27.

De Maio, J., Rinalducci, E. J., Brooks, R., and Brunderman, J. 1983. Visual cuing effectiveness: Comparison of perception and flying performance. Proceedings of the 5th Interservice/ Industry Training Equipment Conference, Washington, D.C., November 14 – 16, 1983, Vol. 1., AD – A142, 774, p. 92-96.

De Maio, J., Schwirzke, M., Matsumoto, J., and Hennessy, R. 1995. Evaluation of the effects of pilotage sensor field of view and location on the performance of disparate flying tasks. Warrendale, PA: SAE. SAE Technical Paper Series 952034.

Delucia, P., and Task, H.L. 1995. Depth and collision judgement using night vision goggles. Int J of Aviation Psychology: 5:371-386.

Durnford, S.J., Crowley, J.S., Rosado, N.R., Harper, J., and DeRoche, S. 1995. Spatial disorientation: a survey of U.S. Army helicopter accidents 1987-1992. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 95-25.

Foyle, D.C., and Kaiser, M.K. 1991. Pilot distance estimation with unaided vision, night vision goggles, and infrared imagery. SID International Symposium Digest of Technical Papers, xxii. SID.

Gibson, E.J., and Bergman, R. 1954. The effect of training on absolute estimation of distance over the ground. Journal of Experimental Psychology. 48: 473-482.

Godfrey, K. 1986. Comparing the means of several groups. In: Bailar JC and Mosteller F. (eds) Medical uses of statistics. Waltham, Massachusetts: New England Journal of Medicine Books.

Hart, D.C. 1994. ADS-33C flight test maneuvers validation in a degraded visual environment. Proceedings of the American Helicopter Society 50th Annual Forum. Washington DC: American Helicopter Society, Inc.

Haworth, L., Szoboszlay, Z., Kasper, E., De Maio, J. and Halmos, Z. 1996. In-flight simulation of visionic field-of-view restrictions on rotorcraft pilot's workload, performance and visual cuing. Proceedings of the American Helicopter Society 52nd Annual Forum. Washington DC: American Helicopter Society, Inc.

Headquarters, Department of the Army. 1988. Night flight: techniques and procedures. TC 1-204. Washington, DC: Headquarters, Department of the Army.

Mizumoto, K., and Utsugi, N. 1975. A study on altitude and distance judgements of pilots during final approach. [English translation from Japanese by Scitran Company, Santa Barbara, CA]. J. JASDF. 15 (4): 179-187.

Niall, K., Reising J.D., and Martin, E.L. 1999. Distance estimation with night vision goggles: a little feedback goes a long way. Human Factors. 41 (3): 495-506.

Rash, C.E., Verona, R.W., and Crowley, J.S. 1990. Human factors and safety considerations of night vision systems flight using thermal imaging systems. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. Report No. 90-10.

Rash, C.E., Vereen, E.A., and McLean, W.E. 1983. Computer program for generating light level calendars of lunar illumination at Fort Rucker, Alabama. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. Letter Report No. 83-4-2-2.

Reising, J.D., and Martin, E. 1995. Distance estimation training with night vision goggles under low illumination (AL/HR-TR-1994-0138). Wright Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.

Rothman, K.J. 1986. Modern epidemiology. Boston: Little, Brown and Company.

Tredici, T. 1996. Ophthalmology in aerospace medicine. In: DeHart RL. Fundamentals of aerospace medicine. 2nd ed. Baltimore: Williams and Wilkins.

Ungs, T.J., and Sangal, S.P. 1990. Perception of near earth altitudes by pilots: ascending vs descending over both a land and water surface. Aviation Space Environmental Medicine. 61:1098-1101.

Verona, R.W., and Rash, C.E. 1989. Human factors and safety considerations of night vision systems flight. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. Report No. 89-12.

Vollmerhausen, R.H., and Nash, C.J. 1989. Design criteria for helicopter night pilotage sensors. Proceedings of the American Helicopter Society 45th Annual Forum. Washington DC: American Helicopter Society, Inc.

Appendix A.

Altitude estimation flight profile.

1. GENERAL: This flight profile has been designed to assess the accuracy of pilot altitude estimation in degraded and non-degraded visual conditions. Subjects will be asked at various times by the research pilot to fly the aircraft to a target altitude (using only the collective control), estimate their altitude over the terrain, or maintain a certain altitude for a specified length of time. During the flight testing, all instruments providing altitude cues (e.g., barometric/radar altimeter, torque, and vertical speed indicator (VSI) are covered or turned off (in the case of the PNVS). Subjects will not receive any altitude cues during the flight from any instrument or from study personnel. The entire profile will take about 30 minutes to fly.

2. MISSION PROFILE:

a. MISSION START: The mission begins at Crows Landing, an airfield operated by the NASA Ames Research Center and located east of San Jose, California. The research pilot will perform a takeoff and proceed around a course that initially heads north but eventually loops back to Crows Landing.

b. CRUISE PHASE: After arriving at the first checkpoint, straight and level at approximately 750 ft/80 kts, the subject will close his eyes upon command from the research pilot. The research pilot will fly the aircraft to an altitude of 500 ft AGL. Upon reaching 500 ft, the research pilot will instruct the subject to open his eyes and adjust the aircraft altitude (using the collective control only) to an altitude of 150 ft. AGL. The research pilot will ensure that airspeed and heading are kept constant. When the subject believes he has achieved the target altitude, he will state, "150 feet." The research pilot then will fly the aircraft back to the first check point, using a cruise altitude of 750 ft AGL. Before beginning the turn back on the original course, the subject will be instructed to close his eyes. The research pilot will descend to 500 ft. AGL while repositioning the aircraft to the original start point. The testing process will be repeated three times. After the third iteration, the subject will be instructed to close his eyes, while the research pilot flies the aircraft to 200 ft AGL/80 knots. The subject will open his eyes and take controls upon cue; his task will be to maintain the current altitude for 30 seconds without reference to instrument altitude cues.

c. APPROACH PHASE: After the cruise phase, the research pilot will fly the aircraft to the approach start point, north of the airfield. The research pilot will then instruct the subject to begin a normal approach to a target placed at the intersection of two dirt roads. When the aircraft is 1.0, 0.8, and 0.35 km from the target, the operator will ask the subject to promptly give an estimate of aircraft altitude AGL upon his "mark." The operator will use the global positioning system (GPS) system and airfield landmarks to cue himself for these distances. The subject's response and the true altitude will be recorded at the ground station.

d. HOVER PHASE: The research pilot will move the aircraft to the designated hover area on the runway overrun, free of buildings or other altitude cues. After instructing the subject to close his/her eyes, the research pilot will climb to 50 ft AGL. The researcher will instruct the subject to open his/her eyes, and adjust the aircraft altitude to 15 ft AGL, maintaining a stable hover and a specified heading. The subject will have 30 seconds to complete the task. When the subject believes he has achieved the target altitude, he will state, "15 feet." This cycle will be repeated three times and will then be followed with the altitude maintenance task (20 ft AGL) in the same fashion as during the cruise phase, except that the subject will be asked to maintain 20 ft AGL for 30 seconds.

e. TERMINATION: The research pilot will return the aircraft to the Crows Landing Airfield ramp and shut down.

3. FLIGHT TEST PARAMETERS: Flight test parameters were recorded on an airborne computer. Pitch, roll, heading, engine torque, sideslip, rate-of-climb, and radar altitude were measured.

Appendix B.

Sample study timetable.

Perception of Self–Altitude in Degraded Visual Environments

Daily Schedule: Mon, 21 Nov 94

Task	Time	Sched. Time	Time done
Admin (consent, overview, quest., eye exam)	30 min	10:30	
FOV fitting	15 min	11:00	
Flt profile brief	15 min	11:15	
ANVIS/FLIR brief	30 min	11:30	
IHADSS fitting	30 min	12:00	
FOV final fitting	15 min	12:30	
Fly to Crow's Lnding	45 min	12:45	
Preflight FLITE acft	15 min	13:30	
FLITE orientation	15 min	13:45	
Day data flight/training	45 min	14:00	
Day 40 deg data flight	30 min	14:45	
GPU FLIR training	30 min	15:15	
Dinner	variable	15:45	
SUNSET		17:00	
Preflight FLITE/brief	15 min	20:00	
ANVIS setup/focusing	15 min	20:15	
Start NVG flight #1	30 min	20:30	
Start NVG flight #2	30 min	21:00	
Start FLIR flight	45 min	21:30	
Close up	30 min	22:15	
Depart Crow's Landing	30 min	22:45	
Arrive Moffett Field		23:15	

NVG flight window:
from: 20:30
to: 22:30

Night flight cond #1: NVG

Night flight cond #2: Mono

Night flight cond #3: FLIR

Today's weather at Crow's Landing:

(FLIR–LAST CONDITION)

Ground time: 04:15

Appendix C.

Volunteer screening questionnaire.

Name______________________________________ SSN: ________________ Age: ___ DOB:__________

GENERAL HEALTH:
Date of last physical examination:

Are you on flight status with a current up slip? NO YES - If no, why not?

Are you in good health currently? NO YES - If no, why not?

Do you have any medical waivers? NO YES - Please describe your waivers

Do you have any profiles? NO YES - Please describe your profiles

Have you taken any medication within the past 3 days? NO YES - If yes, please describe

Do you wear glasses (spectacles) at any time? NO YES

Do you wear contact lenses at any time? NO YES

How do you rate your depth perception ability (circle one) a. below average b. average c. above average

FLIGHT EXPERIENCE: Total flight time: _____ AH-1 flight time: _____

Civilian flight time: _____

PNVS flight time: _____ time since last PNVS flight: _____

ANVIS flight time: _____ time since last ANVIS flight: _____

What aircraft are you rated in?

FOLLOWING TO BE COMPLETED BY AN INVESTIGATOR ONLY

Visual acuity:	near		far	
	sc	cc	sc	cc
OD	20/____	20/____	20/____	20/____
OS	20/____	20/____	20/____	20/____

Stereotest-Circles (32 in.)

____ last test chosen correctly

____ angle of stereopsis (40 passes)

____ initials of examiner

Qualified for study? NO YES
Reason for disqualification:

____________________ Principal Investigator

__________ Date

Appendix D.

Post-study questionnaire.

Name_______________________________ SSN: ______________ Age: ___ DOB:_________

Did you complete all scheduled flights today?	NO	YES - If no, why not?		
In which visual condition did you feel you judged your altitude most accurately? Why?	Day	ANVIS (2 eyes)	ANVIS (1 eye)	PNVS
Did your previous experience with ANVIS help you in this study?	NO	YES - Please describe		
Did your lack of experience with the PNVS hurt you in this study?	NO	YES - Please describe		
Did you experience any motion sickness during any of the testing today?	NO	YES - If yes, please describe		

Thank you very much for your participation.

Please feel free to write any comments you may have about this study.